

UNCLASSIFIED

AD NUMBER

AD809790

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors;
Administrative/Operational Use; DEC 1996. Other requests shall be referred to Ballistic Research Lab., Aberdeen Proving Ground, MD.

AUTHORITY

BRL ltr, 20 Feb 1981

THIS PAGE IS UNCLASSIFIED

**THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.**

DISTRIBUTION STATEMENT A

**APPROVED FOR PUBLIC RELEASE,
DISTRIBUTION UNLIMITED.**

BRL R 1349

809790

BRL

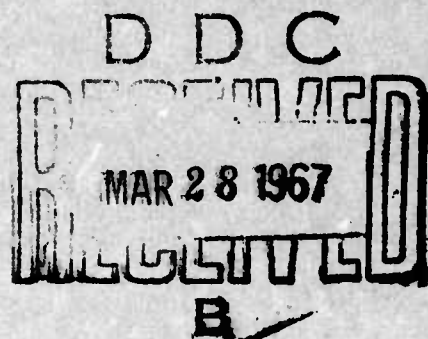
AD

REPORT NO. 1349

DETERMINATION OF PERFORMANCE PARAMETERS FOR FIN-STABILIZED FREE-FLIGHT MISSILES

by

Robert F. Lieske
Joseph W. Kochenderfer



December 1966

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Commanding Officer, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland

U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

Destroy this report when it is no longer needed.
Do not return it to the originator.

The findings in this report are not to be construed as
an official Department of the Army position, unless
so designated by other authorized documents.

BALLISTIC RESEARCH LABORATORIES

REPORT NO. 1349

DECEMBER 1966

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Commanding Officer, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland

**DETERMINATION OF PERFORMANCE PARAMETERS FOR
FIN-STABILIZED FREE-FLIGHT MISSILES**

**Robert F. Lieske
Joseph W. Kochenderfer**

Computing Laboratory

RDT & E Project No. 1P523801A287

ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

REPORT NO. 1349

**RFLieske/JWKochenderfer/bg
Aberdeen Proving Ground, Md.
December 1966**

**DETERMINATION OF PERFORMANCE PARAMETERS FOR
FIN-STABILIZED FREE-FLIGHT MISSILES**

ABSTRACT

The methods used by the Firing Tables Branch for the analysis of flight tests of fin-stabilized, free-flight missiles are outlined. Examples of obtaining thrust and aerodynamic drag from reduction of camera data with the aid of high speed computers are given. Determination of various performance parameters needed for the construction of firing tables is explained; some typical results are presented.

PAGES NOT FILMED ARE BLANK

TABLE OF CONTENTS

	Page
ABSTRACT.....	3
TABLE OF SYMBOLS.....	7
INTRODUCTION.....	11
FREE-FLIGHT MISSILE TEST PROGRAM.....	11
REDUCTION OF FLIGHT TEST DATA FOR DRAG COEFFICIENT (K_D) AND THRUST (T) FORCES.....	13
FLIGHT SIMULATION OF FREE-FLIGHT MISSILES.....	16
CONCLUSION.....	19
REFERENCES.....	29
DISTRIBUTION LIST.....	31

TABLE OF SYMBOLS

Term	Definition	Unit
A_e	Area of jet exit	ft^2
AZ	Azimuth of line of fire (clockwise from North)	deg
$B(t)$	Transverse moment of inertia at time t	lbm-ft^2
C	Ballistic coefficient	lbm/in^2
d	Reference diameter of missile	ft
\vec{E}	Position of the missile with respect to spherical Earth surface	ft
F	Deceleration due to friction	ft/sec^2
\vec{g}	Acceleration vector due to gravity	ft/sec^2
g_o	Acceleration due to gravity (surface)	ft/sec^2
g_c	Constant used in the conversion of $\text{lbf-sec}^2/\text{ft}$ to lbm	lbm-ft/lbf-sec^2
\vec{h}	Angular momentum divided by $B(t)$	rad/sec
h_{2l}	h_2 at end of launch (t_l)	rad/sec
h_{3l}	h_3 at end of launch (t_l)	rad/sec
\vec{H}	Total angular momentum	$\text{lbm-ft}^2 - \text{rad/sec}$
$\dot{\vec{H}}$	Rate of change of H	$\text{lbm-ft}^2 - \text{rad/sec}^2$
I_{SP}	Specific impulse per unit of fuel mass	lbf-sec/lbm
I_{ST}	Total impulse at standard conditions	lbf-sec
K_D	Effective drag force coefficient	_____
K_{DB}	Drag force coefficient during thrust-on	_____
K_{D0}	Zero yaw drag force coefficient	_____
$K_{D\alpha}$	Yaw drag force coefficient	$1/\text{rad}^2$
K_H	Damping moment coefficient	_____

TABLE OF SYMBOLS (Contd)

Term	Definition	Unit
K_L	Lift force coefficient	_____
K_M	Overturning moment coefficient	_____
K_S	Pitching force coefficient	_____
L	Latitude of launch point	deg
m	Mass of missile	lbm
$m(t)$	Mass of missile at time t	lbm
$m_{t_{BST}}$	Mass of missile at end of thrust-on phase at standard conditions	lbm
m_f	Mass of fuel	lbm
$m_{f_{ST}}$	Mass of fuel at standard conditions	lbm
$\dot{m}(t)$	Rate of change of mass at time t	lbm/sec
P_a	Static atmospheric pressure	lbf/ft ²
P_e	Jet pressure at nozzle exit	lbf/ft ²
PE	Probable error	_____
PT	Propellant temperature	°F
QE	Quadrant elevation	°
r	Distance between center of Earth and projectile	ft
r_e	Distance from CG of missile to nozzle exit	ft
r_t	Distance from CG of missile to nozzle throat	ft
R	Radius of Earth	ft
t	Time	sec
t_B	Motor burnout time	sec
t_{BM}	Time from motor ignition until first motion	sec
t_{BMST}	Time from motor ignition until first motion at standard conditions	sec

TABLE OF SYMBOLS (Contd)

Term	Definition	Unit
t_{BST}	Motor burnout time at standard conditions	sec
T	Thrust	lbf
T^*	Effective thrust	lbf
T_F	Thrust factor	_____
$T_R(t)$	Thrust produced by motor at time t	lbf
\vec{u}	Velocity of missile with respect to ground	ft/sec
$\dot{\vec{u}}$	Acceleration of missile with respect to ground	ft/sec ²
\vec{v}	Velocity of missile with respect to air	ft/sec
\vec{w}	Velocity of air with respect to ground	ft/sec
\vec{x}	Unit vector along longitudinal axis of missile	_____
$\dot{\vec{x}}$	Rate of change of \vec{x}	rad/sec
\vec{X}	Position of missile with respect to ground-fixed coordinate system	ft
α	Yaw of missile	deg
$\vec{\Lambda}$	Coriolis acceleration due to rotation of Earth	ft/sec ²
ρ	Air density (varies with altitude)	lbm/ft ³
ϕ	Angle of elevation of launch	deg
Ω	Angular velocity of the Earth	rad/sec
.	Dot - when superscripted, eg. \dot{u} , denotes first derivative as a function of time - when appearing between vectors, eg. $\vec{v} \cdot \vec{x}$, denotes a dot product	
\times	Denotes cross product of vectors	

INTRODUCTION

The purpose of this report is to describe the methods used by the Ballistic Research Laboratories in determining performance parameters for fin-stabilized, free-flight missiles for use in generating firing tables. The work presented herein is derived from a simplified version of a general rigid body mathematical model described in BRL Report No. 1244.^{1*}

FREE-FLIGHT MISSILE TEST PROGRAM

A firing program for production missiles is designed to determine the performance of a free-flight missile system. This program, or matrix, outlines the specific conditions of quadrant elevation (QE) and propellant temperature (PT) under which the rounds are fired. A typical matrix defining a test program is shown below.

QE (m)	Number of Missiles			
	PT (°F)			
	-40	20	77	120
100	4	4	4	4
200	4	4	4	4
400	4	4	4	4
800	4	4	4	4

This array permits determination of motor performance as a function of propellant temperature, and launcher-missile performance as a function of quadrant elevation. The missiles are fired singly from at least two launchers.

The following data are collected for each round.

1. Missile pre-flight measurements
 - a. Weight of components
 - b. Center of gravity, with and without propellant
 - c. Moment of inertia, with and without propellant

* Superscript numbers denote references which may be found on page 29.

- d. Propellant temperature
- e. Fuze setting
- f. Warhead type
- 2. Missile in-flight measurements
 - a. Positions, velocities, and accelerations from camera data
 - (1) From ignition to clear of launcher at 100 frames per second
 - (2) From launcher to point beyond maximum velocity at 30 frames per second
 - (3) From maximum velocity to terminal event at 5 frames per second
 - b. Roll data
- 3. Missile post-flight measurements
 - a. Position of impact (range, height and deflection)
 - b. Time of impact
- 4. Launcher measurements
 - a. Tactical emplacement, before and after firing
 - b. Quadrant elevation, before and after firing
 - c. Azimuth of fire, before and after firing
 - d. Survey of position, before and after firing
 - e. Type and serial number
- 5. Meteorological measurements
 - a. Winds
 - (1) Recorded at five-second intervals at the launch site before, during, and after firing from 0 to 100 feet above the launcher
 - (2) By balloon at a location and time as close to the launch site and firing time as possible
 - (a) From 0 to 1000 feet above the launcher recorded at thirty-second intervals during ascent
 - (b) From surface to a height greater than the expected maximum ordinate of the missile recorded at sixty-second intervals during ascent
 - b. Atmospheric data (pressure, temperature and density)
 - (1) At the launch site at the time of fire

- (2) By balloon at a location and time as close to the launch site and firing time as possible from surface to a height greater than the expected maximum ordinate of the missile recorded at sixty-second intervals during ascent.

REDUCTION OF FLIGHT TEST DATA FOR DRAG COEFFICIENT (K_D) AND THRUST (T) FORCES

The drag force and ultimately the drag coefficient and the thrust forces are determined by an inverse solution of the point-mass differential equations of motion. The drag force is obtained from the free-flight portion of the trajectory, and the thrust force is found from the boost phase. Two assumptions are made to carry out the latter phase.

1. The drag force during boost is small in comparison to the thrust force and is the same as that found for free-flight with estimated changes to the drag force to account for the presence of the jet.

2. An initial thrust curve is assumed along with the following equation to determine the mass flow rate.

$$(1.1) \quad \dot{m}(t) = -T_R(t)/I_{SP},$$

where $\dot{m}(t)$ = Rate of change of mass at time t ,
 $T_R(t)$ = Thrust produced by motor at time t and
 I_{SP} = Specific impulse per unit of fuel mass.

The equations used for the determination of the drag and thrust forces are

$$(1.2) \quad K_D = -[(u_1 - w_1)(\dot{u}_1 + g_1 + \Lambda_1) + u_2(\dot{u}_2 + g_2 + \Lambda_2) + (u_3 - w_3)(\dot{u}_3 + g_3 + \Lambda_3)] m/\rho d^2 v^3 \text{ and}$$

$$(1.3) \quad T = \{ [(u_1 - w_1)(\dot{u}_1 + g_1 + \Lambda_1) + u_2(\dot{u}_2 + g_2 + \Lambda_2) + (u_3 - w_3)(\dot{u}_3 + g_3 + \Lambda_3)] m(t)/g_c v + (\rho d^2 v^2/g_c) K_{D_B} - (P_e - P_a) A_e \} (m_{f_{ST}}/m_f).$$

The approximation of the force of gravity is

$$(1.4) \quad \underline{g} = \left(-g_0 R^2 / r^3 \right) \begin{bmatrix} X_1 \\ X_2 + R \\ X_3 \end{bmatrix},$$

where $r = [X_1^2 + (X_2 + R)^2 + X_3^2]^{1/2},$

g_0 = Value of gravity at point of launch,

r = Distance between center of Earth and projectile,

R = Radius of Earth, and

X = Position of missile with respect to ground-fixed coordinate system.

The Coriolis acceleration due to rotation of the Earth is

$$(1.5) \quad \underline{\Lambda} = \begin{bmatrix} -\lambda_1 u_2 - \lambda_2 u_3 \\ \lambda_1 u_1 + \lambda_3 u_3 \\ \lambda_2 u_1 - \lambda_3 u_2 \end{bmatrix}.$$

For the Northern Hemisphere the λ 's are defined by the following equations [for the Southern Hemisphere replace L by $(-L)$]:

$$\lambda_1 = 2 \Omega \cos L \sin AZ,$$

$$\lambda_2 = 2 \Omega \sin L \text{ and}$$

$$\lambda_3 = 2 \Omega \cos L \cos AZ,$$

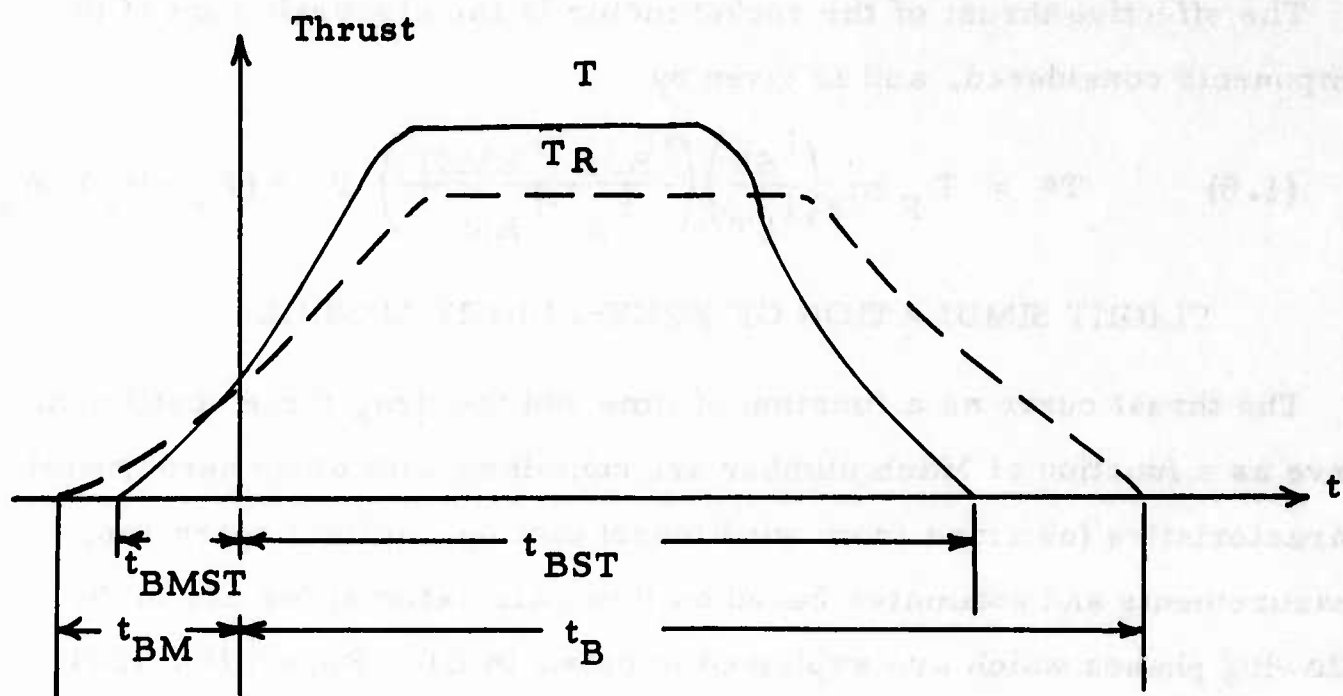
where AZ = Azimuth of line of fire (clockwise from North),

L = Latitude of launch point and

Ω = Angular velocity of the Earth.

The mass of the individual missile, the atmospheric conditions at time of firing and the reduced camera data provide the necessary inputs to solve Equations (1.2) and (1.3) for drag and thrust. Examples of the results of this method of reduction are presented as Figures 1 and 2.

The thrust-time history of a rocket motor as a function of propellant temperature is obtained by assuming a linear transformation of the standard propellant temperature thrust curve in time.



Let

$$(1.6) \quad T = f \left[(t - t_{BM}) \left(\frac{t_{BST} - t_{BMST}}{t_B - t_{BM}} \right) + t_{BMST} \right],$$

where $f []$ indicates "a function of"

The thrust of the rocket motor as a function of time may be linearly transformed, maintaining the same total impulse, by the following equation:

$$(1.7) \quad T_R = m_f \left(\frac{I_{SP}}{I_{ST}} \right) \left(\frac{t_{BST} \quad -t_{BMST}}{t_B \quad -t_{BM}} \right) T.$$

The force due to jet pressure at the rocket nozzle is given by $P_e A_e$.

The static atmospheric pressure produces a force equal to $-P_a A_e$.

The total thrust contributed by pressure is then given by $(P_e - P_a) A_e$.

The effective thrust of the rocket motor is the algebraic sum of the components considered, and is given by

$$(1.8) \quad T^* = T_F m_f \left(\frac{I_{SP}}{I_{ST}} \right) \left(\frac{t_{BST} \quad -t_{BMST}}{t_B \quad -t_{BM}} \right) T + (P_e - P_a) A_e.$$

FLIGHT SIMULATION OF FREE-FLIGHT MISSILES

The thrust curve as a function of time and the drag force coefficient curve as a function of Mach number are combined with other aerodynamic characteristics (obtained from wind tunnel testing, inflight spark range measurements and estimates based on flow calculations) for use in the following phases which are explained in detail in BRL Report No. 1244:¹

1. Launching phase

$$(2.1) \quad \dot{\vec{u}} = \begin{bmatrix} \frac{g_c T^*}{m(t)} \cos \phi \quad \frac{-\rho d^2}{m(t)} K_{DB} v^2 \cos \phi \\ -g_0 \sin \phi \cos \phi \quad -F \cos^2 \phi \\ \hline \frac{g_c T^*}{m(t)} \sin \phi \quad \frac{-\rho d^2}{m(t)} K_{DB} v^2 \sin \phi \\ -g_0 \sin^2 \phi \quad -F \cos \phi \sin \phi \\ \hline 0 \end{bmatrix}.$$

2. Boost phase (rigid projectile)

$$(2.2) \quad \dot{\underline{u}} = - \frac{\rho d^2}{m(t)} (K_{D_B} + K_{D_\alpha} \alpha^2) \underline{v} \underline{v} + \frac{\rho d^2}{m(t)} K_L [\underline{v}^2 \underline{x} - (\underline{v} \cdot \underline{x}) \underline{v}] \\ + \frac{\rho d^3}{m(t) B(t)} K_S \underline{v} (\underline{x} \times \underline{H}) + \underline{g} + \underline{\Delta} + \frac{g_c T^*}{m(t)} \underline{x},$$

$$(2.3) \quad \dot{\underline{H}} = \rho d^3 K_M \underline{v} (\underline{v} \times \underline{x}) + \frac{\rho d^4}{B(t)} K_H \underline{v} [(\underline{H} \cdot \underline{x}) \underline{x} - \underline{H}] \\ + \frac{(\dot{m}(t) r_e r_t)}{B(t)} [\underline{H} - (\underline{H} \cdot \underline{x}) \underline{x}] \text{ and}$$

$$(2.4) \quad \dot{\underline{x}} = (\underline{H} \times \underline{x}) / B(t).$$

3. Free-flight phase (point mass)

$$(2.5) \quad \dot{\underline{u}} = - (\rho m_{t_{BST}} / 144 m C) \underline{v} \underline{v} + \underline{g} + \underline{\Delta},$$

$$(2.6) \quad \underline{X} = \int_0^t \underline{u} dt \text{ and}$$

$$(2.7) \quad \underline{E} = \begin{bmatrix} X_1 \\ X_2 + R - (R^2 - X_1^2)^{\frac{1}{2}} \\ X_3 \end{bmatrix}.$$

In the interest of economy, flight simulations are carried out by two distinct, but combined, phases. The boost portion is simulated by the use of the rigid-body model mentioned above, and the point-mass model is used in the free-flight phase. Since any initial yawing motion of a fin-stabilized, free-flight missile is essentially damped out by motor burnout time, no degradation of result occurs from simulation of the free-flight phase with a point-mass model.

Individual missile weights and measures and the atmospheric conditions at the time of firing are used by the simulator with certain chosen variables to match the flight of the missile at two key points along the trajectory. These key points are obtained by the camera instrumentation and are

1. Velocity vector at a time shortly after motor burnout and
2. Range and height of terminal event.

The velocity vector is matched iteratively by

1. A multiplier (T_F) on thrust applied to the thrust curve to obtain the magnitude of the velocity vector and
2. Initial angular velocities in the vertical ($h_{3\ell}$) and horizontal ($h_{2\ell}$) planes at the time of launch to match the total angle of the velocity vector. These are merely pseudo rates to enable the simulator to match the missile attitude.

The range is matched iteratively by the simulator through the use of an inverse multiplier (C) on the drag curve.

Some additional comparisons are made to determine exactness of the simulation. These are

1. Velocity at end of launch,
2. Position of missile at time of match of velocity vector ,
3. Position of missile and velocity vector at a point approximately 2 seconds beyond time of match of velocity vector ,
4. Position of missile and velocity vector near maximum ordinate, and
5. Deflection and time of flight at terminal event .

When these comparisons are made to the degree of accuracy desired, the following performance parameters for a free-flight missile are obtained:

1. Effective drag force coefficient as a function of Mach number as determined from the drag reduction. (Fig. 3)
2. Thrust as a function of time as determined from the thrust reduction. (Fig. 4)

3. Burning time of motor as a function of propellant temperature as determined from the thrust reduction. (Fig. 5)
4. Thrust factor (T_F) as a function of propellant temperature. (Fig. 6) This represents the effect of propellant temperature on the total impulse of the rocket motor; therefore, the observed probable error in thrust factor is representative of the probable error in impulse.
5. Initial angular velocities ($h_{2\ell}$ and $h_{3\ell}$) as functions of quadrant elevation. (Figs. 7 and 8)
6. Ballistic coefficient (C) as a function of quadrant elevation. (Fig. 9)

On Figures 6 through 9 the solid line indicates the mean performance values of the particular parameter; whereas, the dashed lines present an idea of the dispersion of that parameter.

CONCLUSION

The methods described above have been used successfully to describe the Littlejohn and Honest John flight performance and in preparing adequate firing tables for those weapon systems.

ROBERT F. LIESKE

JOSEPH W. KOCHENDERFER

Effective Drag Force Coefficient (K_D) vs Mach No.

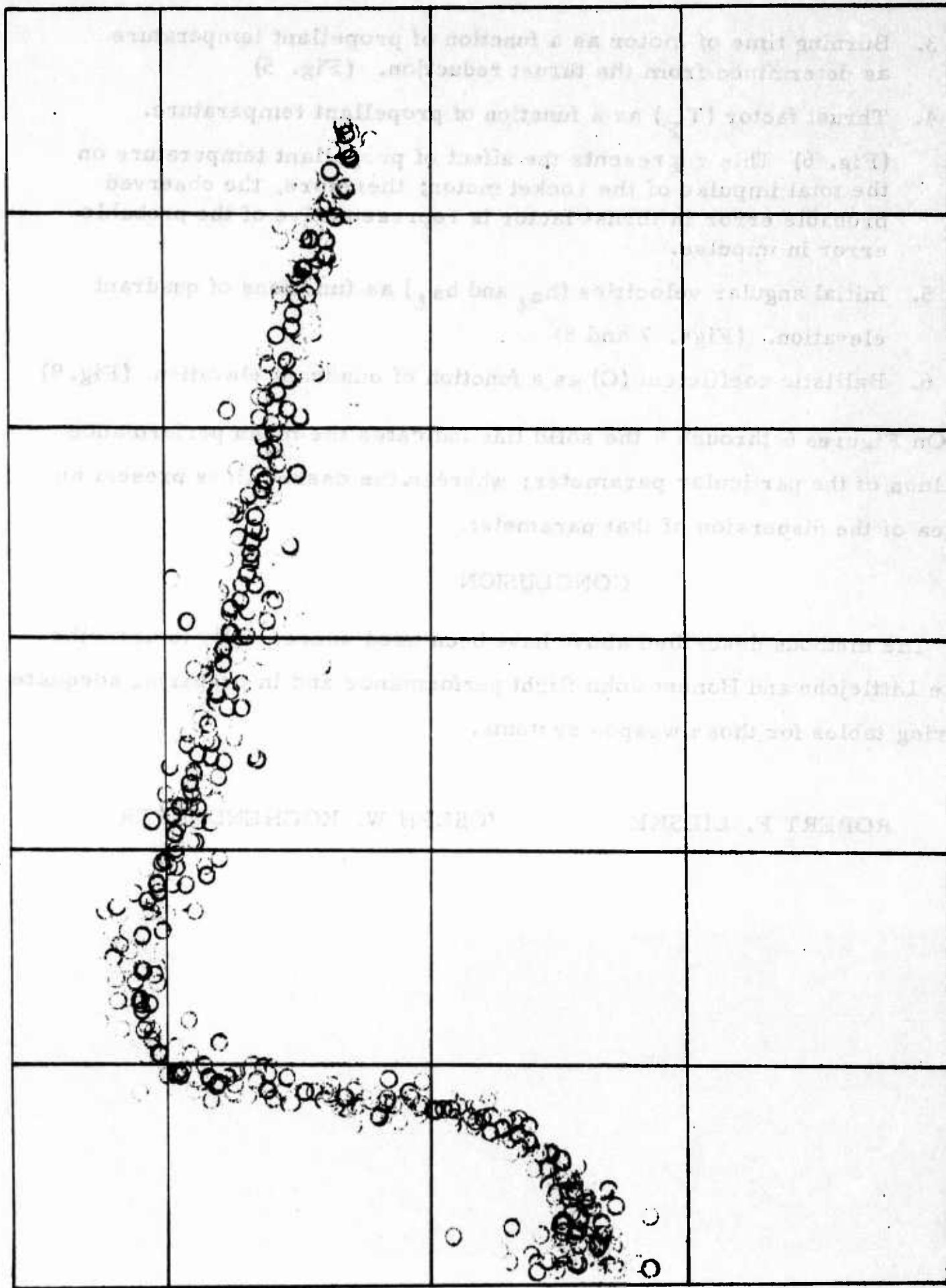


Figure 1

Mach No.

K_D

Thrust vs Time

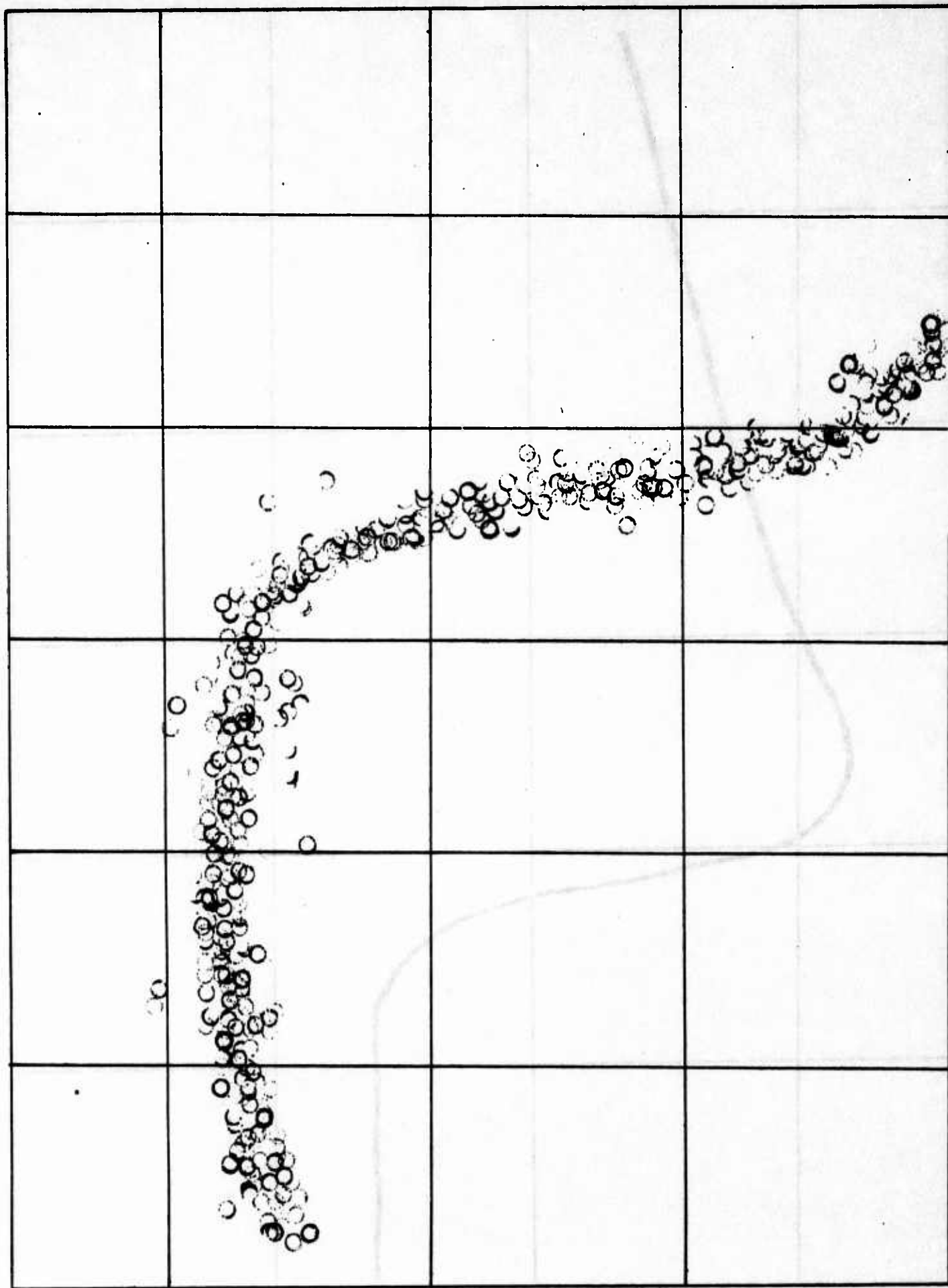


Figure 2

Time

Thrust

Drag Force Coefficient (K_{Do}) vs Mach No.

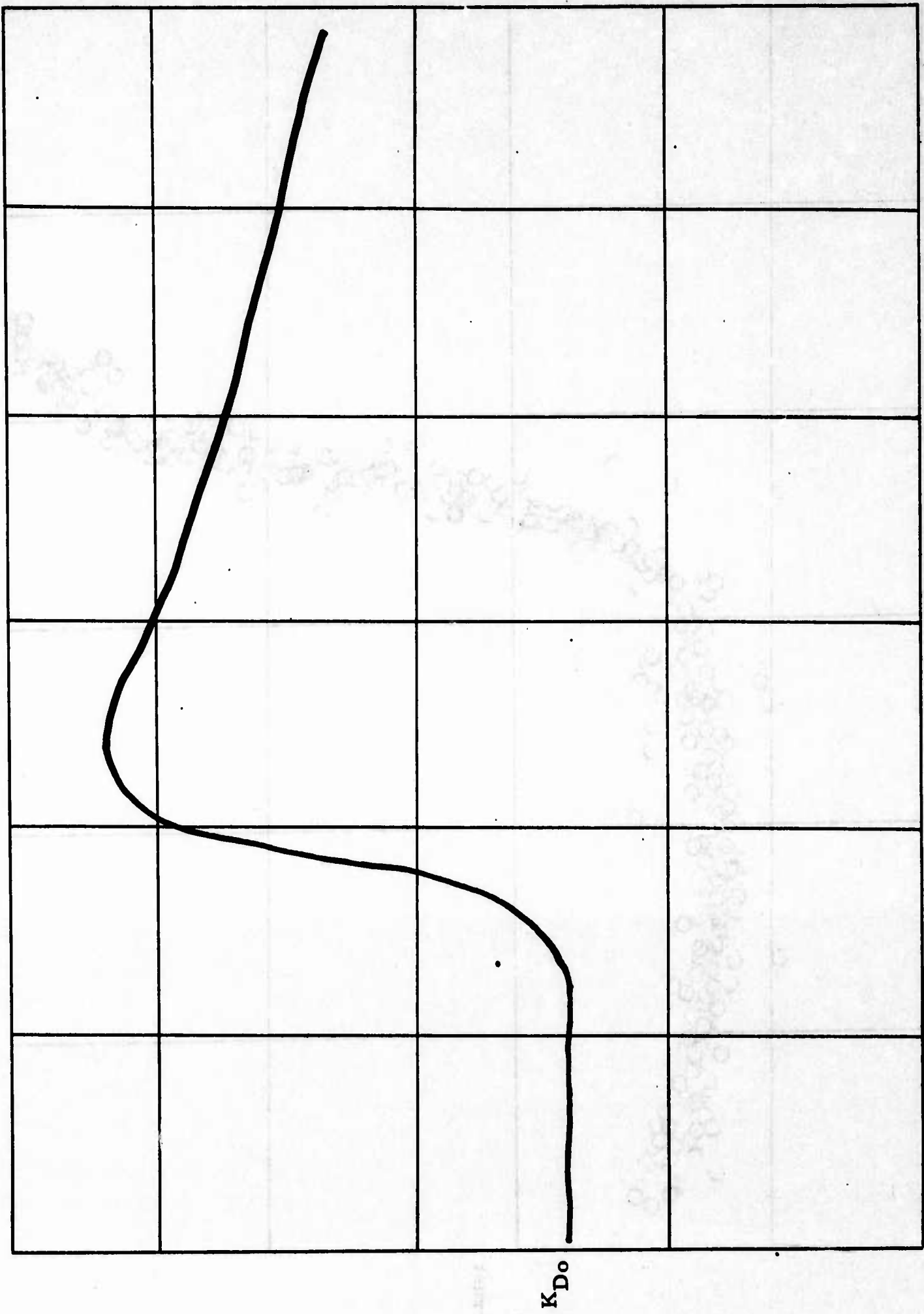


Figure 3

Mach No.

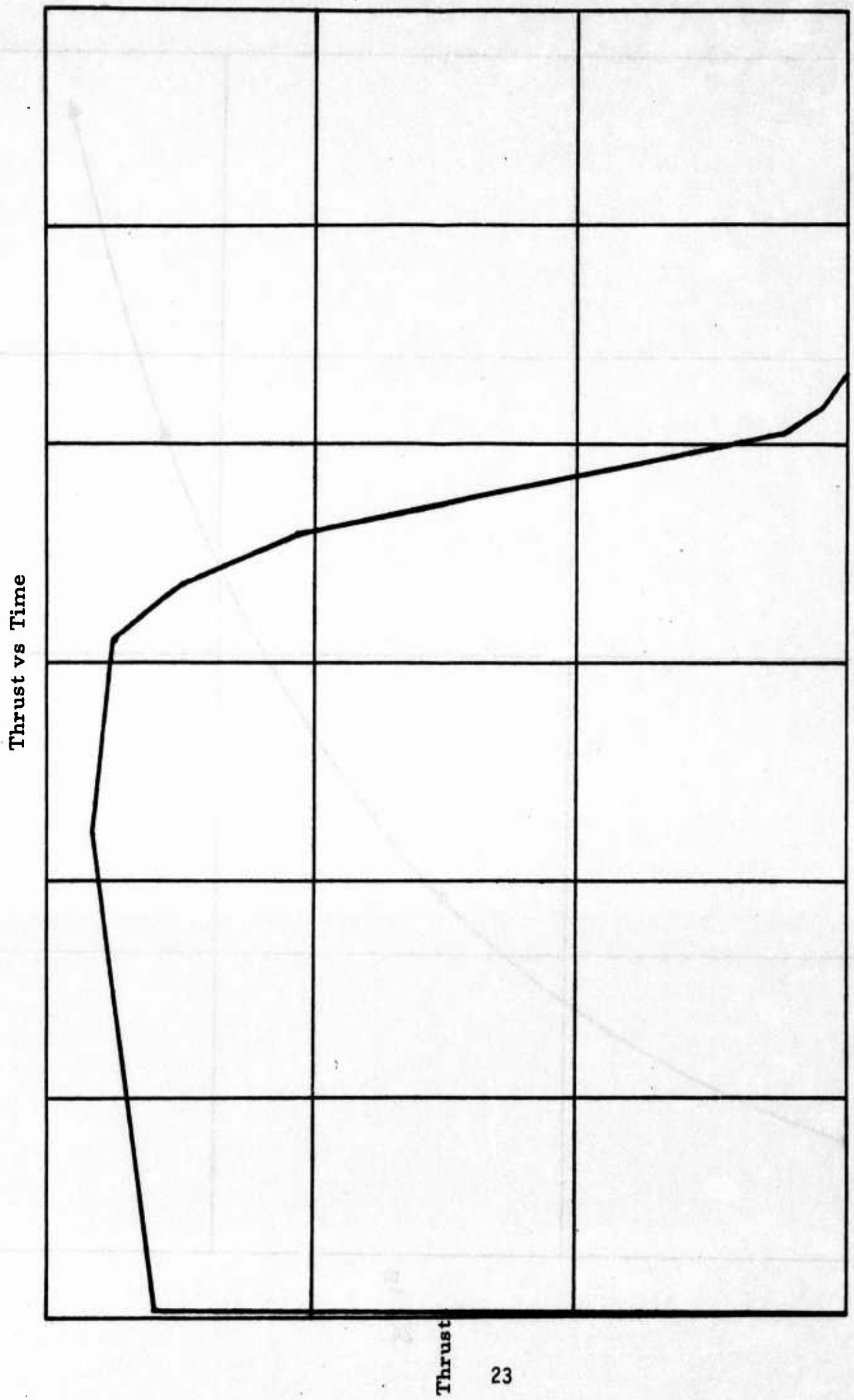
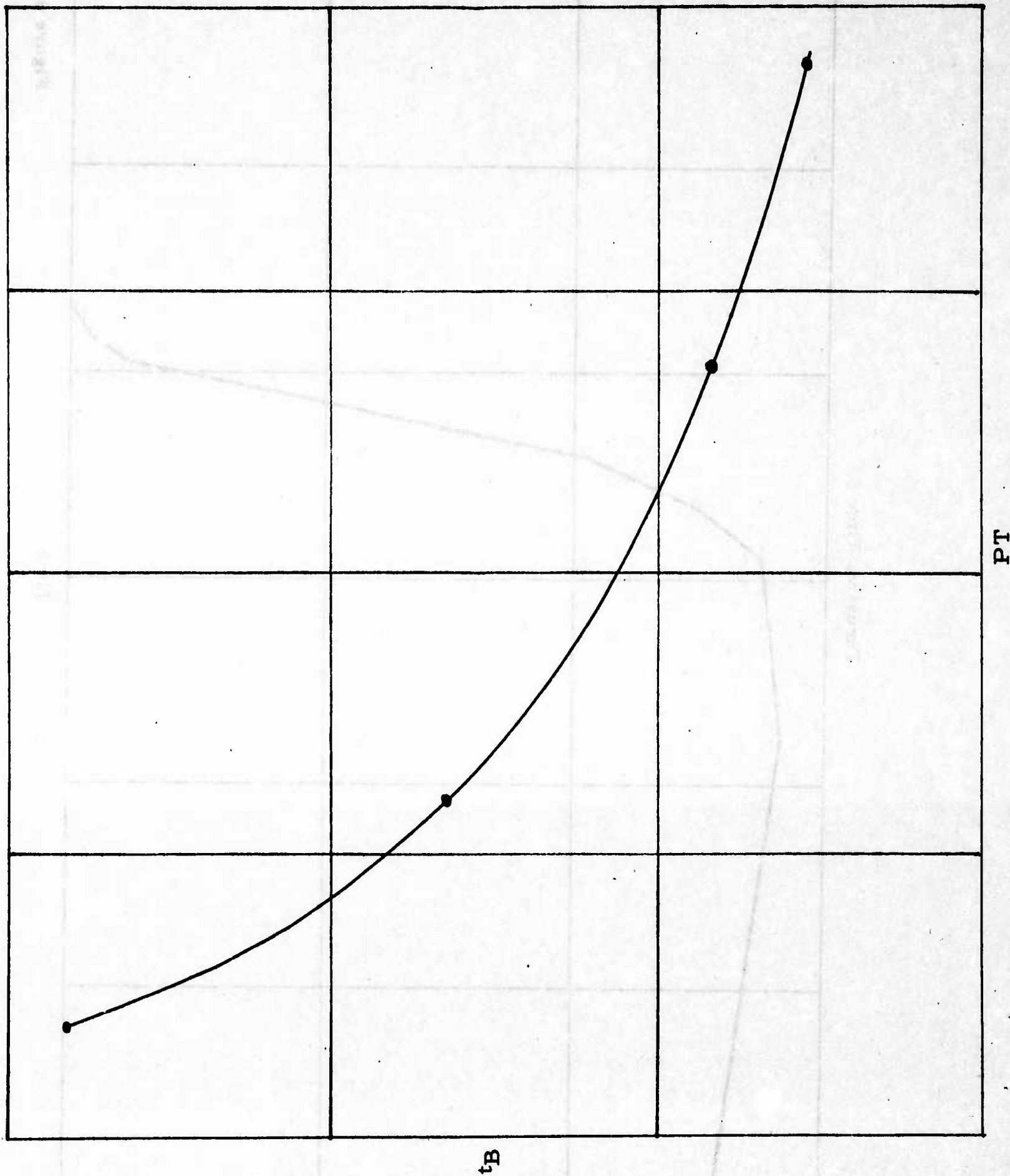


Figure 4

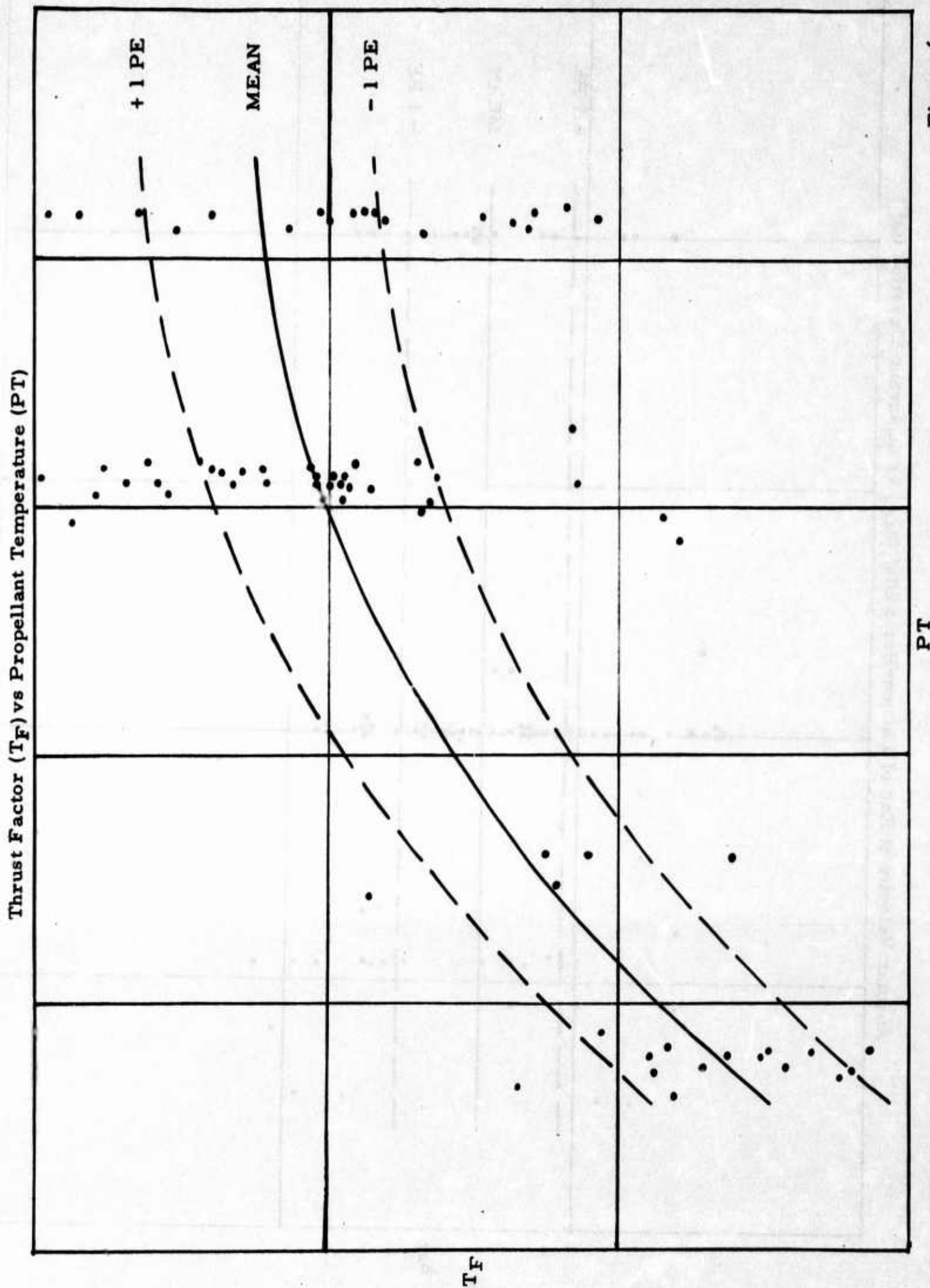
Thrust

Motor Burnout Time (t_B) vs Propellant Temperature (PT)

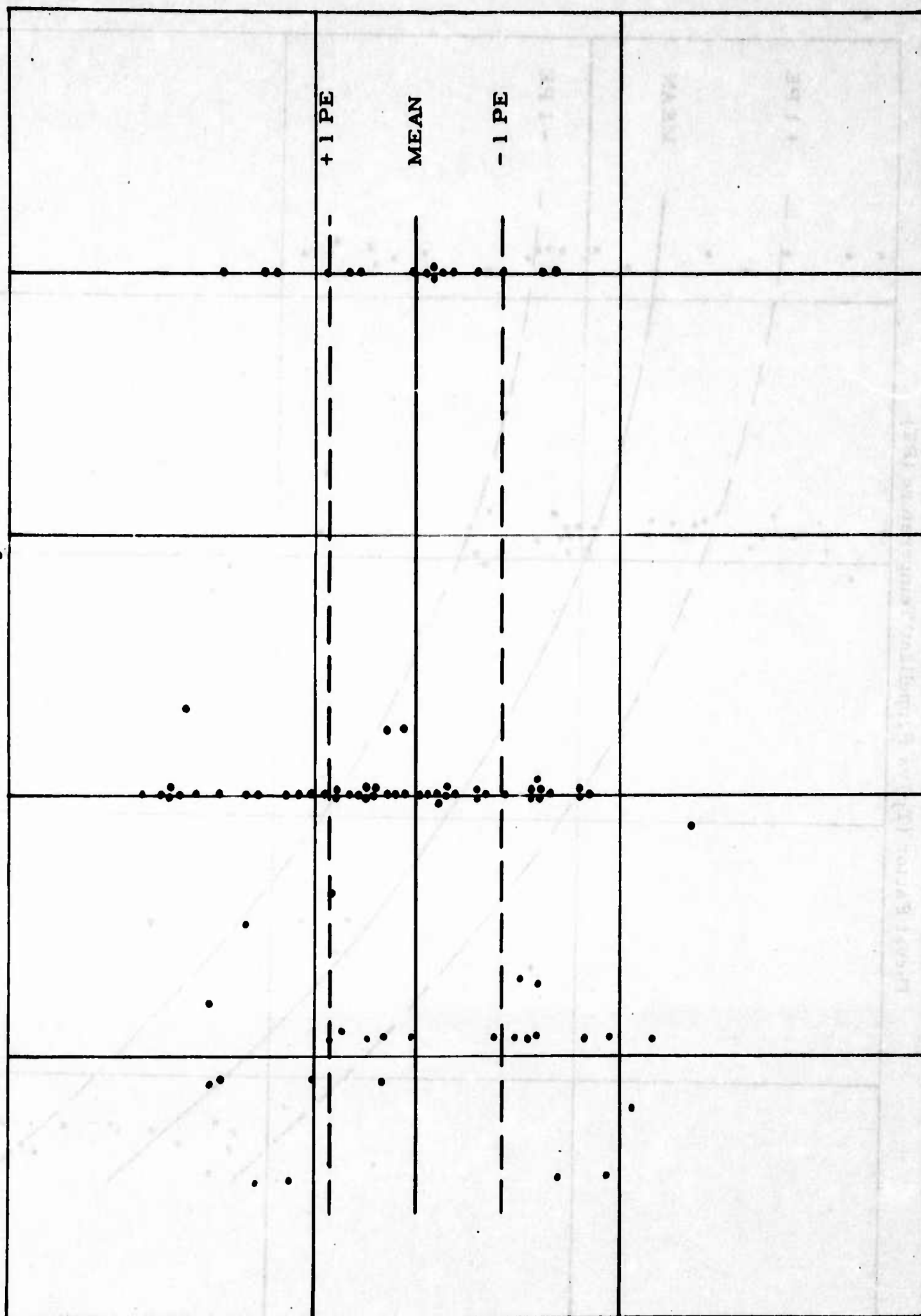


PT

Figure 5



Angular Velocity at End of Launch-Horizontal (h_{2L}) vs Quadrant Elevation (QE)



Angular Velocity at End of Launch-Vertical (h_{3t}) vs Quadrant Elevation (QE)

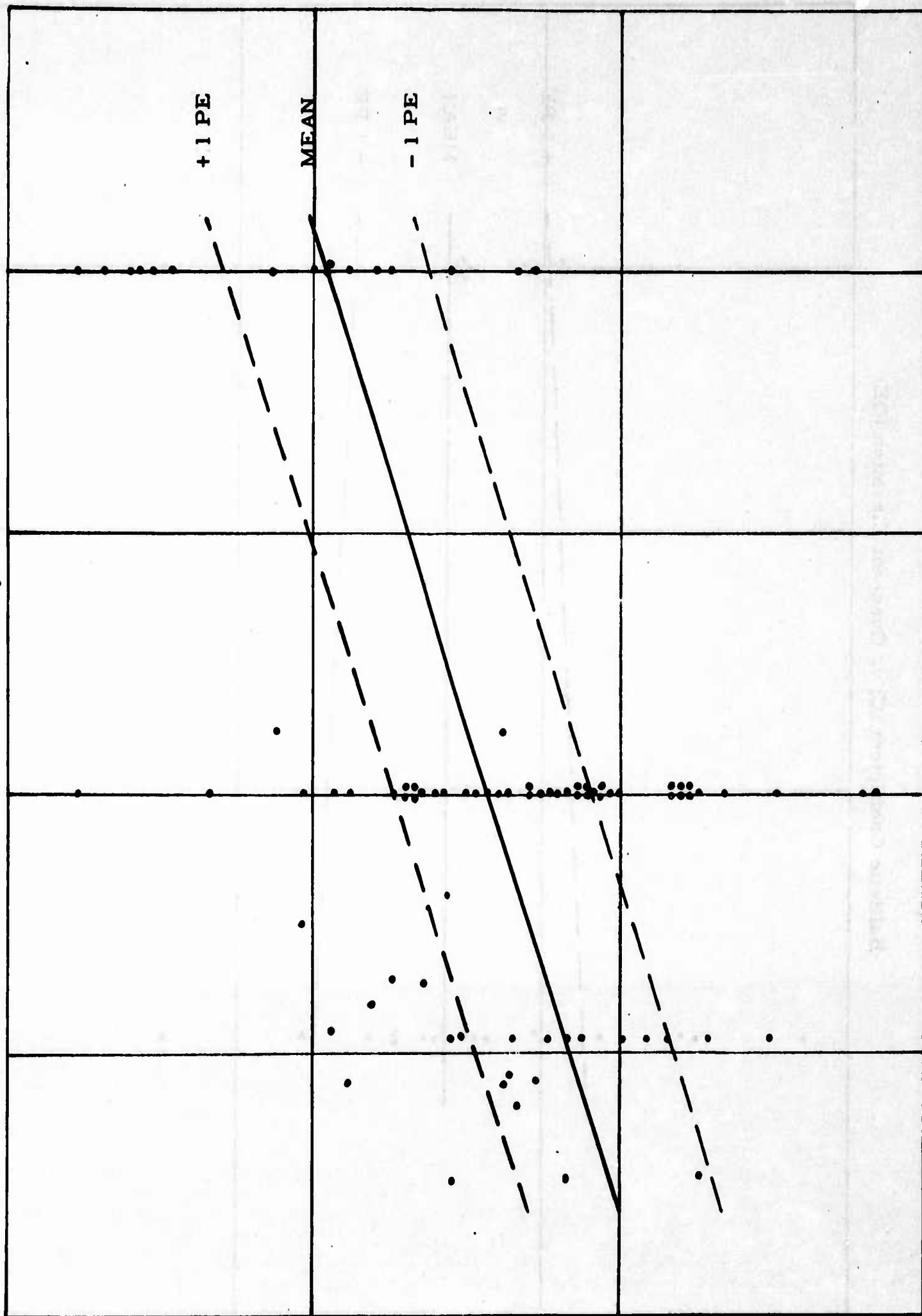


Figure 8

QE

h_{3t}

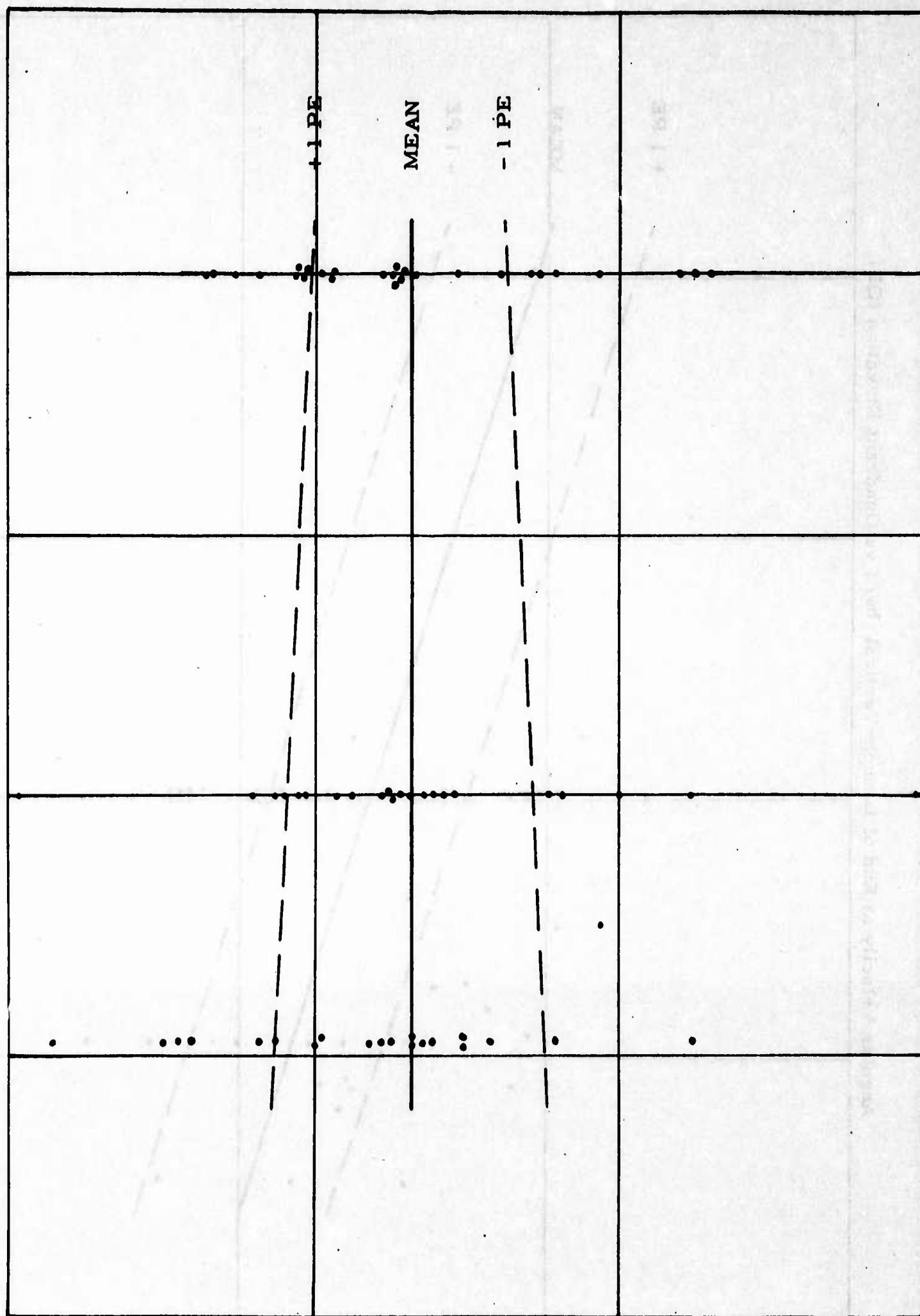


Figure 9

REFERENCES

1. Lieske, R. F., and McCoy, R. L., Equations of Motion of a Rigid Projectile, BRL Report No. 1244, March 1964.
2. Rosser, B. J., Newton, R. R., and Gross, G. L. Mathematical Theory of Rocket Flight, New York and London, McGraw-Hill Book Company, Inc., 1947.

DOCUMENT CONTROL DATA - R&D (Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Ballistic Research Laboratories Aberdeen Proving Ground, Maryland		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE DETERMINATION OF PERFORMANCE PARAMETERS FOR FIN-STABILIZED FREE-FLIGHT MISSILES		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (Last name, first name, initial) Lieske, Robert F. and Kochenderfer, Joseph W.		
6. REPORT DATE December 1966	7a. TOTAL NO. OF PAGES 32	7b. NO. OF REFS 2
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) Report No. 1349	
b. PROJECT NO. 1P523801A287		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. AVAILABILITY/LIMITATION NOTICES This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Commanding Officer, U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Materiel Command Washington, D. C.	
13. ABSTRACT The methods used by the Firing Tables Branch for the analysis of flight tests of fin-stabilized, free-flight missiles are outlined. Examples of obtaining thrust and aerodynamic drag from reduction of camera data with the aid of high speed computers are given. Determination of various performance parameters needed for the construction of firing tables is explained: some typical results are presented.		

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ballistics Missile Performance Equations of Motion Aerodynamic Drag Motor Thrust Firing Tables						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.